STEM Detectives – A New Twist for STEM in the 21st Century

A Blue-Sky Paper on Sciences, Experimentation, Technology, & Measurement

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Students need to learn how to become STEM detectives, not necessarily as an end for a career, but as a responsible tenant in life. Being at ease with experimentation, technology and measurement are key current and future century experiences we must plan for in PK/JK schools. This concentrated view of STEM (Science, Experimentation, Technology and Measurement) does not ignore the practical application of engineering, nor mathematics; rather it highlights experimentation as a process, and measurement as a part of Math, that will be argued fits well within the context of science.

Sciences

The pace of change and discovery in the various fields of science over the past and current centuries continues to accelerate, so much so that what young people need to know has outgrown science as a single subject. Apart from redesigning schedules to afford more time for sciences, schools need to re-define the discipline as multiple sciences. Mechanical, civil, electrical, computer, mining, software, aerospace, computer, robotics engineering fit more with the study of physical sciences, whereas can be a mix of chemical engineering and bio-medical engineering are a mix of chemistry, biology and physics. The expansion of science applications with the rapidly changing field of engineering, reveals the need for schools to not only re-think how science is taught in schools, but how to change the conventional weight of time afforded to this discipline. To become scientists, students need time to apply experimentation practices, use effective technology and be skilled at measurement within a full scope of physical, chemical and biological sciences. How the study of each science genre can unfold for all students is worthy of further discussion.

The teaching and learning of Science can be designed to increase student engagement. As noted, "It can be incredibly engaging when students experience the 'hands-on' habits of a scientists' life, and while learning to think, and interact like scientists with other scientists, is complicated, it is much more authentic than living inside a textbook" (Smith, 2019) Makerspace websites offer a plethora of ideas for motivating young scientists. In addition to rich resources shred by the National Science Teachers Association (NSTA), the following websites have incredible potential for cultivating engaging Science programming: makezine.com; facebook.com/MindShift.KQED/; kickstarter.com; and 1001pallets.com). There are many 'hands on-' and stimulating activities that if implemented on a more widespread basis, might yield an increase in Science students in high school classrooms. Figure 1 illustrates a collection of such ideas.

Figure 1: Stimulating Activities for Science Classes

Stimulating Activities to Do in Science Classes	
• Design an amusement park • Make an animal den • Design a space colony • Design and manage a greenhouse • Hatch eggs • Renovate an animal sanctuary or zoo • Make ice cream • Make furniture • Design a future space station • Design your own deck/cottage • Create own insect project • Toy factory project • Build a Rube Goldberg machine • Create a model of the Canada Arm • Build a robot; launch a rocket	• Crime Scene Investigation (forensics) • Make a microwave oven • Apply for a patent • Instrument making project • Bee Keeping • Make a watershed • Build a monarch butterflies sanctuary • Reducing roadkill project • Create your own atom project • Build and fly a drone • Make a brick • Build a car or golf cart • Design and build a tree fort • Kickstarter campaigns • Design an ideal hospital or school

To reduce the potential overlap and repetition of such activities, a rigorous scope and sequence of science topics and concepts is necessary. As noted: "At the classroom level, teachers need to know how their choices link to a vertical progression of Science concepts, so that everyone does not wind up making volcanoes every year" (Smith, 2019). To this, I added:

> While some content areas of Science tend to fit more with older elementary grades (i.e. circuits and electricity), there are many topics that are not bound by a vertical progression of knowledge. Rocks and minerals, for instance, is a unit typically taught in grades 3, 4 or 5; there is nowhere in the research that claims that it must be taught in one specific grade. It is, therefore, a challenge for curriculum designers to determine which units to teach in which grades.

In two schools, we arranged for students to take part in the *NASA Space Cam*p experience in Huntsville, Alabama, during their March Break. In one of the schools, a group of families signed up for the parent-child program. Emulating what real astronauts and rocket scientists do during the simulations is impossible to replicate in a textbook and classroom. The costs of such programs are significant, but the memories made – priceless. As noted: "The cost may seem extravagant… but such an investment in younger STEM students could be valuable preparation for building a larger critical mass of scientists in the future."

Technology

The T for Technology is a part of STEM, but it is also a part of all disciplines. In a Physics classroom, technology can play a key role in programming robotic machines, creating CAD designs and generating 3D models. In a Botany classroom, video footage can gather growth images over time. In a Chemistry lab, computer timing devices can document exact measures of reaction times. In all science classrooms, various software can be used for documenting results (written reports, charting graphs, generating images of observations), and gathering pre- or post-information about various experiments from the web. Computer engineering can also be considered a discipline within Mathematics in High School, or as a separate subject on its own. The teaching of software use within various Science classes should be a clear blended target, as not all students will have such a rich context for application. Any tool used in any classroom must have time allotted to teach and learn its most effective use. As noted:

> I would argue that technology is a tool; while it requires deliberate teaching, it needs to be applied in multiple discipline areas. While students need to learn how to use specific software such as Excel, PowerPoint, CAD, databases, etc., the days of using technology only in a computer lab should be reconsidered (Smith, 2019).

Experimentation

There is an established framework in Science for conducting experiments: The Scientific Method. The common language in this method includes writing a **hypothesi**s, listing **materials**, stating **a method or procedure**, making a **prediction**, illustrating, labelling and recording **observations**, drawing **conclusions** and acknowledging **bias or sources of error**. Students from Texas in fourth through twelfth grade experimented "in cutting-edge research on an insect called the corn earworm" (Jemison, 2016, p. 62) that caused more than $1 billion dollars' worth of damage each year to farms. Students worked alongside experts in a local USDA/ARS lab. "Students make daily observations of the insect's life cycle. Then they design an experiment to help find new ways to control the insect's damage to crops. The students grow their own corn crop to study" (p. 62). Students need to learn the protocol scientists follow, so that other scientists can systematically replicate experiments to determine if the results are more widespread. In the real-world scientists are prompted to engage in experimentation based on the need to solve real-world problems. The Scientific Method tends to be more cyclic, as scientists usually begin experimenting based on where other experiments left off. In school, the Science curriculum tends to present experimentation as a linear process, usually without much if any prior reading or understanding of the experiments leading to an experiment. The traditional Scientific Method might be strengthened if students were able to compare their results to what is already known – or have their experiment lead to other phases of experimentation and solutions to real problems. As noted, "Science can be much more than proving or disproving a hypothesis using the scientific method" (Smith, 2019). Stanford University has partnered with some local schools to support the notion of Design Thinking According to Lor (2017) "design thinking uses the sensibilities or mindsets and methodologies often used by designers to create new ideas, solutions, alternatives and choices that satisfy the desires of the end users or stakeholders" (p. 40). Rauth, Koppen, Jobst & Meinel (2010) claimed that design thinking contributed to building creative confidence'. Many researchers support the notion of design thinking for creative problem solving

(Fischer, 2015; Dunne & Martin, 2006; Johansson-Skoldberg & Wodilla, 2013; Donar, 2011; Schlenker, 2014). Figure 2 outlines the key components of a Design Thinking method based on student actions.
Figure 2: Components of Design Thinking and Student Actions

Actions	***Students…***
Understand	• talk to experts and conduct research • develop background knowledge • use their findings as a "springboard" to address design challenges
Observe	• watch how people behave and interact • observe physical spaces and places • talk to people about what they are doing, ask questions and reflect on what they see • develop a sense of empathy
Point of View	• focus is on becoming aware of peoples' needs and developing insights • use the phrase "How might we...." to determine a point of view • suggest how to make changes that will have an impact on peoples' experiences
Ideate	• brainstorm ideas and to "suspend judgment" • do not see any idea as "far-fetched" • do not reject ideas from others • embrace quantity of ideas • can generate hundreds of ideas in one sitting • engage in creative and fun experience • become "silly, savvy, risk takers, wishful thinkers and dreamers of the impossible...and the possible..."
Prototype	• create rough sketches or models to convey an idea quickly • learn that it is better to fail early and often as they create prototypes
Test	• go back to prototype and modify based on feedback • learn what works and what doesn't work for their users

Adapted from https://web.stanford.edu/dept/SUSE/taking-design/presentations/Taking-design-to-school.pdf

Quality Science programming in the 21st Century involves students conducting conventional experiments as well being exposed to the process of design thinking.

Measurement

Rather than referring to the 'M' as 'Mathematics', this vision of STEM focuses on M for 'measurement'. The quality of an observations is often linked to the precision of measurement. As a high school Physics teacher, the cries of my colleagues, still resonate for me today. "*The students do not have a grasp of the math needed to work with these formulas*". Often, we were teaching Math within our classrooms outside the scope and sequence of how the math concepts might best be taught in a progressive manner. It does not do much good to teach the algebraic formulas needed for advanced Physics application in isolation of the Mathematics program. Rather, the timing of when such complex applications are required need to be organized after students have mastered the Math needed for the application. In other words, the Physics that requires the such formulas should happen in more senior high school classrooms, well after the mastery has been established in earlier grades.

Developing the skill of making precise measurements, on the other hand, can be a strand, within Science from PK/JK to twelfth grade. Students at a young age are encouraged to use non-standard measures to compare the width and length of random objects in a typical Mathematics class, but they could be using fingertips to measure the amount of water it takes to float a pumpkin, or the number of logs it takes to build a bridge. Measurement can be a more authentic skill and understanding if taught as a strand within Science. By the time students are in third grade, they are ready to determine the difference between measures to determine which tool to employ to gain the most accurate results. They should also be able to move freely between metric and empirical measures by the time they are in the middle grades. Moving the measurement strand from Mathematics to Science can be advantageous in two ways: students can learn to use the measurement tools in the context on an authentic learning situation; and students can have more time left for mastering other strands (whole numbers, parts numbers, and geometry) within their pure Mathematics courses. The teaching of geometry within Mathematics would also reinforce the measure of 2D and 3D measures. When students are involved in building projects (shelters, outdoor theatres, fences, etc. where they must apply the principles of Physics, measurement plays a key role, and therefore needs to be taught as part of the project, not assumed it has been mastered elsewhere. Such an approach to the 'M' in STEM involved further dialogue about moving the teaching of measurement into specific Science classes, and if educators are ready to accept that Science is too big to be taught as a single entity, then there can be ample room for coordinating the teaching of measurement within Biology, Zoology, Botany, Physics and Chemistry.

Helping students become STEM detectives is about preparing future biologists, physicians, zoologists, veterinarians, botanists, florists, engineers, pipefitters, chemists, pharmacists, inventors, and so on. How can we re-think the parameters of STEM to prepare for the 21st century and beyond?

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"If we teach today as we taught yesterday, we rob our children of tomorrow." ~ John Dewey

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